CMSC 330: Organization of Programming Languages

Objects and Functional Programming
OOP vs. FP

- **Object-oriented programming (OOP)**
  - Computation as interactions between objects
  - Objects encapsulate state, which is usually mutable
    - Accessed / modified via object’s public methods

- **Functional programming (FP)**
  - Computation as evaluation of functions
    - Mutable data used to improve efficiency
  - Higher-order functions implemented as closures
    - Closure = function + environment
Relating Objects to Closures

• An object...
  • Is a collection of fields (data)
  • ...and methods (code)
  • When a method is invoked
    ➢ Method has implicit this parameter that can be used to access fields of object

• A closure...
  • Is a pointer to an environment (data)
  • ...and a function body (code)
  • When a closure is invoked
    ➢ Function has implicit environment that can be used to access variables
Relating Objects to Closures

class C {
    int x = 0;
    void set_x(int y) { x = y; }
    int get_x() { return x; }
}

let make () =
    let x = ref 0 in
    ( fun y -> x := y,
      fun () -> !x )

C c = new C();
c.set_x(3);
int y = c.get_x();

fun y -> x := y
fun () -> !x

let (set, get) = make ();
set 3;;
let y = get ;;
Encoding Objects with Closures

- We can apply this transformation in general

\[
\text{class C} \{ \text{ f1 ... fn; m1 ... mn; } \}
\]

- becomes

\[
\text{let make () =}
\text{ let f1 = ...}
\text{ ...}
\text{ and fn = ... in}
\text{ ( fun ... , (* body of m1 *)}
\text{ ...}
\text{ fun ... , (* body of mn *)}
\]

- make () is like the constructor
- The closure environment contains the fields
Quiz 1: Is Circle Encoded Correctly?

class Circle {
    float r = 0;
    void set_r (float t) { r = t; }
    float get_r () { return r; }
    float area(){
        return 3.14 * r * r;
    }
}

C c = new Circle();
c.set_r(1.0);
float y = c.get_r();
c.area();

A. True
B. False

let make () =
    let r = 0.0 in
    ((fun y -> let r = y in ()),
     (fun () -> r),
     fun ()-> r *. r *. 3.14
    )

let (set_r, get_r, area) = make ();;
set_r 1.0;;
let y = get_r();;
area();;
Quiz 1: Is Circle Encoded Correctly?

```c
class Circle {
    float r = 0;
    void set_r (float t) { r = t; }
    float get_r () { return r; }
    float area() {
        return 3.14 * r * r;
    }
}

C c = new Circle();
c.set_r(1.0);
float y = c.get_r();
c.area();
```

A. True
B. False

```ocaml
let make () =
    let r = ref 0.0 in
    ((fun y -> let r := y in ()),
     (fun () -> !r),
     fun () -> !r *. !r *. 3.14
    )

let (set_r, get_r, area) = make ();;
set_r 1.0;;
let y = get_r();;
Area();;
```
Relating Closures to Objects

- A closure is like an object with a designated `eval()` method
  - The type of `eval` corresponds to the type of the closure’s function, \( T \rightarrow U \)

```java
interface Func<T,U> {
    U eval(T x);
}
class G implements Func<T,U> {
    U eval(T x) { /* body of fn */ }
}
```

- Environment is stored as field(s) of \( G \)
Relating Closures to Objects

```java
interface IntIntFun {
    Integer eval(Integer x);
}
class Add1 implements IntIntFun {
    Integer eval(Integer x) {
        return x + 1;
    }
}
```

```python
let add1 x = x + 1
add1 2;;
add1 3;;
new Add1().eval(2);
new Add1().eval(3)
```
Quiz 2: What does this evaluate to?

```
interface IntIntFun {
    Integer eval(Integer x);
}

class Foo implements IntIntFun {
    Integer eval(Integer x) {
        return x * 2;
    }
}

new Foo(5);
```

A. 5  
B. 10  
C. 6  
D. None of the above
Quiz 2: What does this evaluate to?

```java
interface IntIntFun {
    Integer eval(Integer x);
}

class Foo implements IntIntFun {
    Integer eval(Integer x) {
        return x * 2;
    }
}

new Foo(5);
```

A. 5
B. 10
C. 6
D. None of the above (should be called `new Foo().eval(5)`)

Relating Closures to Objects

```
let app_to_1 f = f 1

interface IntIntFunFun {
  Integer eval(IntIntFun x);
}
class AppToOne
  implements IntIntFunFun {
    Integer eval(IntIntFun f) {
      return f.eval(1);
    }
  }

app_to_1 add1;;
new AppToOne().eval(new Add1());
```
Quiz 3: What does this evaluate to?

```java
interface IntIntFun {
    Integer eval(Integer x);
}
class Foo implements IntIntFun {
    Integer eval(Integer x) {
        return x * 2;
    }
}
interface IntIntFunFun {
    Integer eval(IntIntFun x);
}
class AppToFive implements IntIntFunFun {
    Integer eval(IntIntFun f) {
        return f.eval(5);
    }
}
```

```java
new AppToFive().eval(new Foo());
```

A. 5  
B. 10  
C. 6  
D. Error
Quiz 3: What does this evaluate to?

```java
interface IntIntFun {
    Integer eval(Integer x);
}
class Foo implements IntIntFun {
    Integer eval(Integer x) {
        return x * 2;
    }
}
interface IntIntFunFun {
    Integer eval(IntIntFun x);
}
class AppToFive implements IntIntFunFun {
    Integer eval(IntIntFun f) {
        return f.eval(5);
    }
}
```

new AppToFive().eval(new Foo());

A. 5  
B. 10  
C. 6  
D. Error
Relating Closures to Objects

interface Func\langle T, U \rangle {
    U eval(T x);
}

class Add1 implements Func<Integer, Integer> {
    public Integer eval(Integer x) {
        return x + 1;
    }
}

class AppToOne implements Func<Func<Integer, Integer>, Integer> {
    public Integer eval(Func<Integer, Integer> f) {
        return f.eval(1);
    }
}

app_to_1 add1; new AppToOne().eval(new Add1());
Relating Closures to Objects

```java
class Add implements Func<Int, Func<Int, Int>> {
    private static class AddClosure implements Func<Int, Int> {
        private final Int a;
        AddClosure(Int a) {
            this.a = a;
        }
        Integer eval(Int b) {
            return a + b;
        }
    }
    Func<Int, Int> eval(Int x) {
        return new AddClosure(x);
    }
}
```

```javascript
let a = 1;
let add = add a b = a + b;
let add1 = add 1;
add1.eval(4);

fun b -> a + b
let add1 = add 1;;
add1 4;;

let add a b = a + b;;

Func<Int,Int> add1 = new Add().eval(1);
add1.eval(4);
```
Encoding Closures with Objects

• We can apply this transformation in general

\[
\text{...(fun } x \rightarrow \text{ (* body of fn *))} \ldots
\]
\[
\text{let } h \ f \ \ldots = \ldots f \ y\ldots
\]

• becomes

```java
interface F<T,U> { U eval(T x); }  
class G implements F<T,U> {  
    U eval(T x) { /* body of fn */ }  
}  
class C {  
    Typ1 h(F<Typ2,Typ3> f, ...) {  
        ...f.eval(y)...  
    }  
}  
```

• F is the interface of a closure’s function
• G represents the particular function
Quiz 4: Are these two versions equivalent?

A. True
B. False
Quiz 4: Are these two versions equivalent?

A. True
B. False

let mult x y = x * y
let f = mult 2 in
f 3;;

interface IntIntFun {
    Integer eval(Integer x);
}
class Mult implements IntIntFun {
    private int x;
    Mult(int x) { this.x = x }
    Integer eval(Integer y) {
        return x * y;
    }
}
Mult f = new Mult(2);
f.eval(3);
Recall a Useful Higher-Order Function

- Map applies an arbitrary function \( f \)
  - To each element of a list
  - And returns the results collected in a list
- Can we encode this in Java?
  - Using object-oriented programming
public class MyList {
    private class ConsNode {
        int head;
        MyList tail;
        ConsNode(int h, MyList l) {
            head = h; tail = l;
        }
    }
    private ConsNode contents;
    public MyList () {
        contents = null;
    }
    public MyList(int h, MyList l) {
        contents = new ConsNode (h, l);
    }
    public MyList cons (int h) {
        return new MyList(h, this);
    }
    public int hd () {
        return contents.head;
    }
    public MyList tl () {
        return contents.tail;
    }
    public boolean isNull () {
        return (contents == null);
    }
}
A Map Method for Lists in Java

Problem – Write a map method in Java
  • Must pass a function into another function

Solution
  • Can be done using an object with a known method
  • Use interface to specify what method must be present

```java
public interface IntFunction {
    int eval(int arg);
}
```

(can make this polymorphic but will keep it simpler for now)
A Map Method for Lists (cont.)

- Examples
  - Two classes which both implement `Function` interface

```java
class AddOne implements IntFunction {
    int eval(int arg) {
        return (arg + 1);
    }
}

class MultTwo implements IntFunction {
    int eval(int arg) {
        return (arg * 2);
    }
}
```
The New List Class

class MyList {
    ...
    public MyList map (IntFunction f) {
        if (this.isNull()) return this;
        else return (this.tl()).map(f).cons (f.eval (this.hd()));
    }
}
Applying Map To Lists

- Then to apply the function, we just do

```java
MyList l = ...;
MyList l1 = l.map(new AddOne());
MyList l2 = l.map(new MultTwo());
```

- We make a new object
  - That has a method that performs the function we want
- This is sometimes called a callback
  - Because `map` "calls back" to the object passed into it
- But it’s really just a higher-order function
  - Written more awkwardly
We Can Do This for Fold Also!

• Recall

```ocaml
let rec fold f a = function 
  [] -> a
| (h::t) -> fold f (f a h) t
```

• **Fold** accumulates a value (in `a`) as it traverses a list
• `f` is used to determine how to “fold” the head of a list into `a`

• This can be done in Java using an approach similar to `map`!
A Fold Method for Lists in Java

• Problem – Write a fold method in Java
  • Must pass a function into another function

• Solution
  • Can be done using an object with a known method
  • Use interface to specify what method must be present

```java
public interface IntBinFunction {
    Integer eval(Integer arg1, Integer arg2);
}
```
A Fold Method for Lists (cont.)

- Examples
  - A classes which implements IntBinFunction interface

```
class Sum implements IntBinFunction {
    Integer eval(Integer arg1, Integer arg2) {
        return new Integer(arg1 + arg2);
    }
}
```

- Note: this is not curried
  - How might you make it so?
class MyList {
    ...
    public MyList map (IntFunction f) {
        if (this.isNull()) return this;
        else return (this.tl()).map(f).cons (f.eval (this.hd()));
    }

    public int fold (IntBinFunction f, int a) {
        if (this.isNull()) return a;
        else return (this.tl()).fold(f, f.eval(a, this.hd()));
    }
}
Applying Fold to Lists

- To apply the fold function, we just do this:

```java
MyList l = ...;
int s = l.fold (new Sum(), 0);
```

- The result is that s contains the sum of the elements in l
Java 8 Eases the Syntax

- Java 8 allows you to make objects that act as functions, more easily
  - Instead of this
    ```java
    MyList l = ...;
    MyList l1 = l.map(new AddOne());
    MyList l2 = l.map(new MultTwo());
    ```
  - Write this
    ```java
    MyList l = ...;
    MyList l1 = l.map((x) -> x + 1);
    MyList l2 = l.map((y) -> y * 2);
    ```
Code as Data

- Closures and objects are related
  - Both of them allow
    - Data to be associated with higher-order code
    - Passing code around the program
- The key insight in all of these examples
  - Treat code as if it were data
    - Allowing code to be passed around the program
    - And invoked where it is needed (as callback)
- Approach depends on programming language
  - Higher-order functions (OCaml, Ruby, Lisp)
  - Function pointers (C, C++)
  - Objects with known methods (Java)
Code as Data

- This is a powerful programming technique
  - Solves a number of problems quite elegantly
    - Create new control structures (e.g., Ruby iterators)
    - Add operations to data structures (e.g., visitor pattern)
    - Event-driven programming (e.g., observer pattern)
  - Keeps code separate
    - Clean division between higher & lower-level code
  - Promotes code reuse
    - Lower-level code supports different callbacks